A QUANTITATIVE NET-PLANKTON SURVEY OF EAST AND WEST RESERVOIRS, NEAR AKRON, OHIO.

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INTRODUCTION.

The Lakes.

Plankton investigations of some of the Portage Lakes near Akron, Ohio, were started by the writer several years ago, but the only systematic work done thus far is the brief net-plankton survey of East and West Reservoirs reported in this paper.

The Portage Lakes consitute a chain of lakes south of Akron. Several of the lakes are in part relics of glacial times, and some are largely of artificial origin. East and West Reservoirs are of the latter type but are old and have long been in good biological condition.

East and West Reservoirs are connected by a long, bent channel, which though shallow, is navigable by small boats. West Reservoir, smaller and narrower of the two, is also connected by a similar but somewhat broader and deeper channel to Turkeyfoot Lake, which, with its tributary lakes, Rex Lake and Mud Lake, is the largest of the group. These named above are on the same level. North from East Reservoir is Long Lake, at considerably lower level. It receives overflow water from East Reservoir principally through an outlet at the northern tip of East Reservoir, but also through Snakey River, close to it. New Reservoir, somewhat higher than Long Lake, has overflow into the latter. Long Lake has a long channel, quite wide in places, flowing northward, joining the Ohio Canal, to which Nesmith Lake is also joined. The map will show the complicated connections of these waters, which need not be described in detail. Summit Lake, still farther northward on the Ohio canal, and within the city of Akron, is not shown on the accompanying map, which is adapted from a "Detailed Map of the Portage Lakes and Vicinity," made by W. V. Quine, 1927.

Period of Collections.

This report is based on collections entirely from these two reservoirs, made from April to October inclusive, 1929. Collections were also made in 1928, but none earlier than June 30,

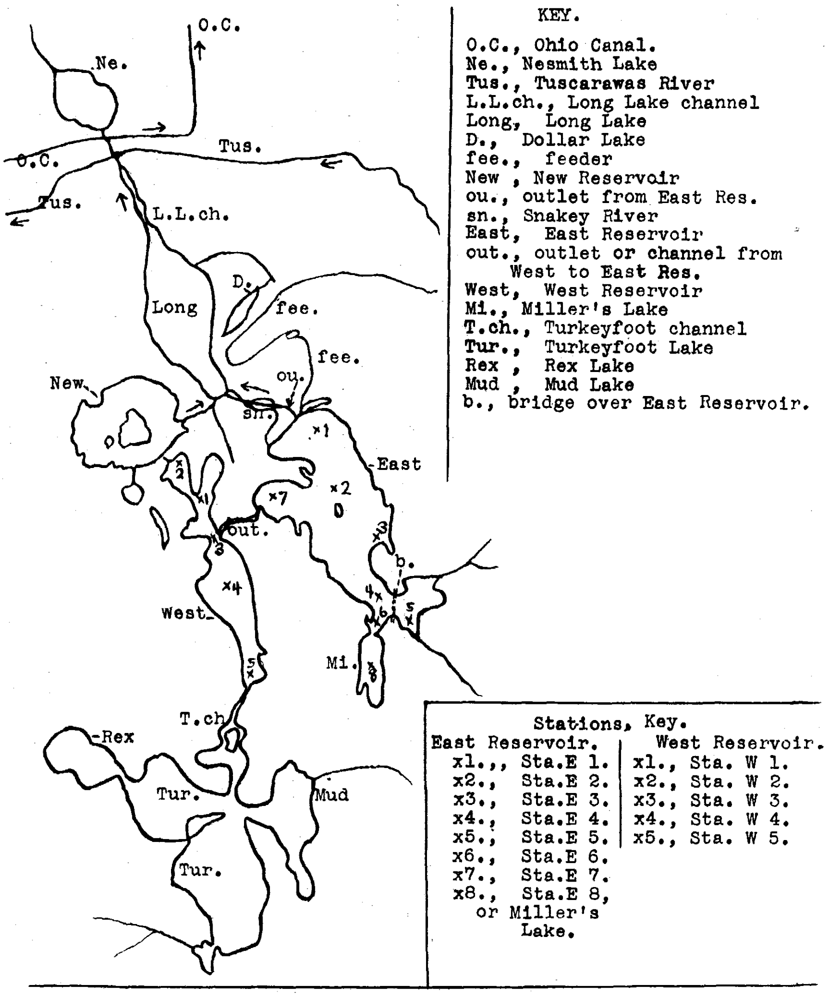

Plate 1. The Portage Lakes, near Akron, Ohio, (Summit Lake omitted), and showing Plankton Stations on East and West Reservoirs.

and unfortunately these were made at different intervals and at different times in the month and especially in the earlier collections, not with the same accuracy and uniformity of method prevailing for the 1929 collections. It was therefore entirely inadvisable to use any counts of the 1928 plankton in close comparison with detailed counts of the 1929 catches presented in this paper. There would be no accuracy in any averages that could be made of those two years. Only through absolute uniformity of method through a period of years would averages be very significant. It has been impossible to continue the same detailed work since, though it is planned for some future time to make a similar one year survey of the same lakes for a later comparative report if that is found advisable. The delay in this report is due to the dependence upon vacation time for all of the microscopical observations and tabulations. In the general discussion of this paper some use is made of a certain late summer 1928 collection, made by chance at a very similar time as a 1929 collection, the comparison concerning only very abundant organisms.

Purposes of the Investigation.

The investigation had these purposes: to get idea of the chief plankton organisms of these lakes and their relative abundance, to get idea of the seasonal distribution, which in this case is the variation from late April to late October, and to get data on horizontal distribution as seen in different stations, and also on vertical distribution, as far as possible in such shallow waters.

Limitations of the Investigation.

The survey was entirely of the net-plankton, not of the nanno-plankton or minutest organisms. It is quantitative, as plankton organism enumeration was carried on throughout. Results are given as so many organisms per liter of lake water. The method of "standard area units," (see Whipple, 1927, pp. 124–5), in which size of organisms is taken into account may be significant in sanitary analysis, but does not appeal to one listing organisms for a biological survey. There is here no bulk measurement of so many cubic centimeters of plankton per cubic meter of water, etc., as expressed by Whipple in his discussion of "standard cubic units," (Whipple, 1927). No weight determinations were made of plankton or of organic matter of the plankton, as recently carried out by Birge and Juday (1922), and others. There was no attempt to make estimates of the productivity of the lakes as for instance of so many grams of organic matter per cubic meter of water.

In connection with this biological investigation no chemical analyses of the water were made, and no physical measurements, except that surface water temperatures were taken. No equipment was available for taking temperatures in deeper water.

The two lakes are shallow, and it seems from a considerable number of soundings made at selection of stations, that depths of over 15 or 18 feet in times of high water, must be few. Large areas of the middle of the lakes may not be over 10 feet deep. Undoubtedly both lakes are shallower than Turkeyfoot Lake.

Acknowledgments.

Thanks are due the Division of Conservation of the Ohio Department of Agriculture, and particularly to Mr. E. L. Wickliff, Chief of the Bureau of Research of that Division for material help in the investigation. The Division purchased the Birge closing, quantitative tow net for the writer, and vials and bottles. Also an outboard motor boat belonging to the conservation warden of the district was at my disposal. The microscopic equipment used and the counting cell belong to the Department of Biology, University of Akron.

I also wish to thank the following for identifications of some plankton organisms: Dr. L. H. Tiffany, for numbers of algæ determinations early in my collections; Dr. Lowell E. Noland, for the identification of the Protozoan Codonella; Mr. Frank J. Myers for identification of rotifers, especially Synchaeta and Anapus, (which he pointed out is now Chromogaster), and in fact for identification to species and variety of all rotifers in some samples sent him. I require only generic names of the commoner forms. He also used the newer genus name Keratella for the older Anuraea, which I venture to retain however, since it will be more readily recognizable by readers. I also wish to thank Prof. Chancey Juday for help in response to many questions on plankton methods I put to him, and likewise Dr. Stillman Wright and Mr. Wilbur Tidd for their replies to questions on their plankton methods.

Methods and Apparatus.

Collecting.

Collections were made with a Birge closing, quantitative, plankton tow net, made by Mr. J. P. Foerst of Wisconsin. The silk bolting cloth was of the very fine mesh, old number 20, new number 25. The collecting method is the old one dating from 1882 (Henson 1887). No other collecting device was used. For this general method see chapters on collecting in Ward and Whipple (1918), and Whipple, (1927).

In figuring the volume of water strained by the net the following results were obtained. The upper net ring diameter being 10 cm., the area of collecting surface, was ($r^2 \times \Pi$), or $5^2 \times 3.1416 = 78.5$ sq. cm. All hauls were made 1M. in length. Hence the water column traversed was a cylinder, 78.5×100 cm. $= 7850$ c.c. or 78.5 liters.

But any fine mesh tow net strains less water actually than the column traversed, as has been noted by various investigators. "The whole column of water through which the net passes is not strained however, since the straining part of the net offers some resistance to the passage of the water and a certain portion of it is pushed aside and not strained. This makes it necessary to determine the efficiency of the net, or the coefficient, which serves as a factor for calculating the total number of organisms in the column of water." (Birge and Juday, 1922, p. 8). And these investigators point out that in addition variations in the quantity of the plankton causes slight irregularities in the actual water strained and that the aging of the net does likewise due to more and more clogging of the net. Mr. Juday supplied the coefficient of the net, which is 2; that is the number of organisms secured in any catch would have to be multiplied by two. Birge, in an early paper, (1896) discussed the problems of net coefficients.

The speed of hauling the net alters the coefficient slightly. In an earlier report, Juday (1896) pointed out that a net drawn 77 cm. per second strained one-half of the water traversed so that the efficiency was 50% or the amounts of plankton secured would have to be multiplied by two. Under other net conditions this might vary. Through some initial trials the writer secured some such speed and the "feel" of the pull of this sort of haul, which is not very fast and can be carried out, was so impressed that a rather uniform haul could be maintained thereafter.

Hauls of the net were not as difficult as they would be in larger bodies of water where there was more wave action. Only seldom was there enough wave motion to make it difficult to read the exact depth on the calibrated line of the net. Surface records so-called were made by hauling the net one M. horizontally, gauged by a M. marked off at edge of boat, holding the net rim just completely submerged in the water.

The collections were made at 5 stations on West Reservoir, and 8 on East Reservoir. These are designated on the map, (Plate I) and on my records as W1 to W5 and E1 to E8. Of the 8 on East Reservoir, the last or E8 is in a tributary Lake, Miller's Lake. For some purposes in this work this is regarded as a separate lake. Station E1 was out in the middle of the northeast arm of the lake, one of the deeper stations; a 3-4 M. haul could be secured there. E2 was in the center of the largest part of the lake, which was shallower however owing to its proximity to a sandbar, and allowed no deeper haul than 1-2 M. Later some deeper spots were discovered some distance off from this station. E3 was nearer shore in a cove, but allowing also a 1-2 M. haul. E4 was near the center of the channel between the two larger parts of the lake, and quite deep, though not allowing quite for a 3-4 M. haul. E5 was in a shallow area not far from shore in a smaller lagoon-like area of the lake, but this part is not cut off from the larger lake, the apparent cut-off on the map being a bridge. E7 was in the middle of the smaller or northwest arm of the lake; and was deep enough for 3-4 M. haul. E8 was in the center of Miller's Lake, tributary to East Reservoir. It was also deep enough for a 3-4 M. haul. On West Reservoir, W1 was in deep water a short distance from a promontory separating the two northern arms of the lake. A 3-4 M. haul could be made there. W2 was in the upper, middle part of one of these arms, and also deep enough for a 3-4 M. haul. W3 was in the middle of the narrow part of the lake where the channel from East Reservoir meets West. W4 was in the center of the largest part of this lake, but an area not deep enough to yield a 3-4 M. haul. W5 was near the southern end of the lake, in the center near that end near the channel which joins Turkeyfoot Lake.

All stations were distinctly off shore enough to escape littoral conditions. No collections were made where surface vegetation like Lemna or Wolffia occurred. No collections were made where the net would in making the actual measured haul upward, be in any dense bottom vegetation. So few depth samples could be secured because always the depth has to be such as to allow the bucket to be free from bottom mud, or nearly 1 M. more than greatest depth sample actually used. Thus only three stations out of eight on East and two stations out of five on West were deep enough for a 3-4 M. haul. In all the rest no deeper haul than 1-2 M. was secured. In all of the stations there was this 1-2 M., haul except at E5, where only the surface haul was made. Late in summer when the water depth decreased, station E5 was moved out farther into the lake.

Hauls of merely one meter may seem short, but longer ones were not feasible if more than one vertical sample was to be secured from such shallow water. There was hope of recognizing some differentiation in water samples, collected at surface and at depths 1-2 M. and again at 3-4 M. The intervening meters of water were not sampled, or the water samples were made discontinuous in hope of showing any existing differences distinctly.

Collections were made on April 20, May 25, June 21, July 20, Aug. 21, Sept. 21, and Oct. 26.

All collections were made in daylight at approximately same time of day. The collections from all stations requiring a minimum of three and one-half hours, were always made in the same sequence, so that even though there were delays in starting or frequently during the work, the light conditions were not materially different in the different trips, except as seasonal or weather differences brought about, and on all collecting days weather was clear except for the April collection when the sky was overcast and a light drizzle fell part of the time.

The plankton water samples were collected in vials from the bottom of the net bucket. A small, uniform amount of water from a wash bottle was used to help wash organisms into the vial. - The samples then varied usually between 10 and 15 or maybe 20 c.c. The exact size of sample at collection is of no significance, provided it is made of uniform size with others by distilled water in subsequent work. About 1-2 c.c. of strong formaldehyde was put into each vial before collecting the lake water into it.

Not all limnoplankton can be secured with the plankton net, as a host of the smallest organisms, the nannoplankton, would escape unless accidentally held in masses with larger organisms. Some organisms observed and even a few counted in this work, may seem to border on this nannoplankton group. But all the smaller organisms included are usually listed as being within net-plankton limits, and the same genera are thus listed for instance by Birge and Juday (1922). These smallest ones listed in this paper occur in such large numbers and with such seasonal variation as is considered normal, that it seems certain that appreciably none were lost through the net or that all were collected in the same proportion as larger organisms.

Microscopy.

The microscopic work was done at intervals, chiefly during summer vacations. Only a part of some 1928 collections were examined, at whatever concentration they were at time of collection, and for most samples counted there was too great a concentration of organisms. In all the work on the extensive 1929 collections, varying small amounts of distilled water were added to the plankton water samples, to make the working plankton sample size a number of c.c. which would be a small decimal or simple fraction of the amount of lake water strained by the net. This would make calculations much simpler later than to take some seemingly simple figures as 10 or 20 c.c. for the working sample. Since the theoretical water column of a net haul was 7850 c.c., a sample size of 7.85 c.c. would have been theoretically good, or on the same basis, a sample size of half that would have immediately given in 1 c.c. examined the number of organisms in a liter of lake water, because the 50% net efficiency would actually collect half the organisms, or organisms of half that actual lake water, and multiplying by 2 would give the actual numbers for the 7850 c.c. But such samples are all too small for practical reasons, such as inability to measure accurately in graduate cylinder, and too great a concentration of organisms. By making concentrate 15.7 c.c. and also in many cases 31.4 c.c. then by a simple multiplication of the number of organisms in 1. c.c. of the concentrate, by 4 or by 8 respectively, gave the number in one liter of lake water. In each case the total concentrate was well stirred in a beaker and 1 c.c. of it pipetted into a Sedgwick-Rafter counting cell, (50 X 20 mm., and 1 mm. deep).

Microscopic examination was done under a Spencer low power binocular, and for more magnification under compound microscope, 16 mm. objective. The binocular was used with its highest magnifying power, $\times$ 46, for examining the entire cell contents. The cell was moved across the stage against a ruler held by clips, and then adjusted the correct distance for another crosswise movement, a definite number of times until the entire 20 mm. width was covered. Complete counts of all larger organisms and indeed for types down to the smallest recognizable with this binocular, were made. Many more were counted in the whole cell than first planned, but these whole counts bring more accurate results than the counts of smaller parts with calculations, as is necessary for the smallest organisms. Thus not only Entomostraca and Rotifers were fully counted, but such as the Protozoan Ceratium and even the filaments of the algal colony Anabaena.

The compound microscope was used for distinguishing and counting smaller planktonts, or those of too great an abundance to count in entire cell. A 16 mm. objective and 7.5 ocular were used. Higher magnifications were not needed for this work, nor was time taken for thin mounts of any planktonts. The Whipple ocular micrometer was used in counting. With the above combination of lenses a tube length of 184 mm. was necessary to have the large square of the Whipple micrometer equal 1 sq. mm. on the stage. The organisms in a cube covered by such square were counted completely. Twenty such fields scattered rather regularly over the entire cell (equal to 1000 such small fields) were taken and examined fully. The total of counts in 20 fields for any organisms multiplied by 50 gave the total number in 1 c.c. of the concentrate, or counting cell.

This standard method of counting and then multiplying to get total numbers, may result in errors of rather large size, if the numbers of organisms involved is rather small, though only neglegible errors if the numbers are large. This was verified in many cases on organisms of such size that they could be counted under binocular, as rotifers Ceratium, Anabaena filaments, as well as Cyclops eggs, Nauplius larvæ, etc. The method of counting all individuals was compared with the other method and discrepancies noted. Actual examples will not be detailed here, except to note that in several instances cases of Ceratium and also rotifers Anuraea and Polyarthra, were found to have when 20 fields were counted and multiplication made, far too high a number assigned, proven by the actual counts of same samples under binocular, in such cases where the numbers were of the order of 100 individuals for entire cell, though when the actual numbers were of an order of 1000 or thereabouts, no real discrepancies occurred.

This matter must be obvious to most plankton investigators, but has not been stressed much in reports. To avoid as far as possible considerable errors in numbers, as large a number of plankton kinds as could be recognized under the binocular, were fully counted for the entire cell, involving often very tedious work.

No complete list of plankton has been attempted. Only limnetic plankton identified to genus and of such occurrence that at least a few would be encountered from time to time were considered for the actual plankton counts, though if a very rare form were large and identifiable, record was kept of it. No estimates were made of partly disintegrated forms.

Discussion of Plankton Collections.

Plankton Kinds and Limitation of Data in Tabulations.

When all plankton counts were made the 1929 collections data were so tabulated that there were 14 tables, one for each monthly collection and each lake, each containing the data of number of planktonts of every kind regularly counted, per liter of lake water, separately for each station and for surface and two depths. Only a few plankton types of large size but very rarely encountered were omitted. These tables are too bulky for presentation. They would show all the minor variations of stations. But since many of the organisms were not commonly found, there would be many blank spaces for absence of various kinds any one month from some or all stations.

The rarely occurring genera that may be noted briefly here included: the Protozoan Vorticella, occurring in small numbers at one station in three collections, the Cladocera Scapholebris and Camptocercus each occurring at only one station in one collection. Also the Ostracod Cypris was found only twice in very small numbers, a surprising rarity considering their abundance in food of some minnows taken in an earlier year, from the same lakes (Kraatz, 1928, and Cassidy, Dobkin and

Wetzel, 1930). Hydra was found in just one collection at one station June 21, (one specimen in surface sample and 4 at 1-2 M.). This meant only 4 Hydra at most in the entire concentrated sample, or less than one per counting cell sample. Presence of this form in the limnetic zone cannot be accounted for. Rarer rotifers included Anarthra, occurring twice in small numbers, and a few others not then identifiable to genus by the writer. Mr. Myers identified to species all rotifers in a few vials sent him, and indicated them as rare, few, common, or abundant. Those he marked rare are omitted from tables, those marked few, referred to (to genus) below, are also omitted from the shortened tables, and only the common and abundant ones are listed to genus in tables in this paper.

Counts were kept of eggs of rotifers, and Cladocera, and of the genus Cyclops. The eggs, often were numerous, especially of Cyclops and rotifers, were however eliminated from the tabulations. A total of 37 distinct genera remain in these longer tables of plankton kinds.

To present more concisely, and at the same time quite fully all the significant comparative data, 20 of the 37 genera were selected on the basis of being the most representative planktonts of these lakes, and either abundant or common, or if seemingly in small numbers, found rather uniformly in many monthly collections. These tabulated (tables 1–7) on basis of monthly collections, show the differences between the lakes, and retain the surface and depths differences but are averages of the several stations on a lake at any one level. Thus at West Reservoir, 5 stations were averaged, at east Reservoir 7 stations were averaged, but No. E8, which is Miller's Lake, tributary to East, was kept distinct.

The plankton types omitted from the tables 1–7, and which were on the whole not as abundant as any included, occurring as very few here or there or in a few cases abundant in one monthly collection, are here listed: the blue-green algæ Merismopoedia, and Oscillatoria, (really abundant in the May collection, and not noticed otherwise); the green algæ, Westella, Staurastrum, Mougeotia; the flagellates (plant or animal) Euglena, Phacus, Synura, Pandorina, Eudorina, and Mallomonas, (which occurred in small numbers in quite a few collections); the Protozoa Arcella and Epistylis; the rotifers Notholca, and Anapus (now called Chromogaster, as Myers pointed out); and the Cladocera Chydoris and Ceriodaphnia.

Since the seasonal distribution is one of the main objectives, the monthly variations were brought together in close comparison, (tables 8–10), one table devoted to each lake, including a separate one for Miller's Lake, and in each case furthermore the plankton number represents an average of all three levels,

TABLE 1.

APRIL 20 COLLECTIONS. COMPARISON BETWEEN LAKES AND OF DEPTHS OF THE PRINCIPAL NET-PLANKTON ORGANISMS.

NAMES OF ORGANISMS	NUMBER OF ORGANISMS PER LITER OF LAKE WATER								
	West Reservoir			East Reservoir			Miller's Lake		
	Surface	1-2 M.	3-4 M.	Surface	1-2 M.	3-4 M.	Surface	1-2 M.	3-4 M.
Coelosphaerium	3								
Microcystis	1								
Anabaena	3								
Aphanizomenon									
Melosira	20,920	20,160	21,800	19,315	15,733	8,200	1,000	1,000	100
Synedra	13,280	10,840	8,660	8,671	4,300	3,200	3,200	1,200	1,200
Asterionella	18,400	19,840	13,000	72,885	54,400	24,800	22,200	9,600	9,600
Fragilaria	1,880	800	1,200	115	171				
Pediastrum	89	17	12	15	15	10			
Dinobryon						2			
Ceratium	5	6	2	1	1		4	4	
Codonella	78	114		850	582	644	76	4	
Polyarthra	744	619	734	916	526	320	368	248	300
Anuraea	2,231	1,937	892	632	437	282	1,040	1,016	
Synchaeta	112	71		33	306	2			
Asplanchna	6	2		1			4		
Nauplius	124	111	290	242	115	70	72	72	108
Cyclops	102	82	106	72	55	62	96	108	304
Daphnia	9	10	14	15	16	12	12	4	16
Bosmina	27	30	16	13	38	8	4	12	
Surf. Tempt.	11° C.			11° C.			11° C.		

surface, 1–2 M. and 3–4 M. This method of presenting the summaries and comparison was chosen rather than graphs, because while graphs are graphic, but only obviously so when arithmetical plot is used, the wide range in numbers for some organisms, as in an extreme case the diatom Asterionella, of hundreds of thousands in one month and then a fluctuation of from several thousands to even a hundred or less for all other months, would require a peak of relatively enormous height in the graph, or most of the other fluctuations of practically microscopic height. Many of the plankton graphs would be more or less of this sort. Or to show fully the main fluctuation,

TABLE 2.

May 25 Collections. Comparisons Between Lakes and of Depths, of the Principal Net-plankton Organisms.

Names of Organisms	Number of Organisms per Liter of Lake Water								
	West Reservoir			East Reservoir			Miller's Lake		
	Surface	1-2 M.	3-4 M.	Surface	1-2 M.	3-4 M.	Surface	1-2 M.	3-4 M.
Coelosphaerium	30	57	384	25	24	44		32	
Microcystis	27	34	8		60				
Anabaena	464	968	452	299	246	132	32	8	8
Aphanizomenon									
Melosira	7,040	20,720	800	9,829	15,066	12,600	3,800	4,400	8,000
Synedra	7,520	10,080	200	48,600	46,266	30,400	41,200	27,600	24,400
Asterionella	99,160	209,841	217,400	204,228	460,700	304,400	302,800	396,000	380,000
Fragilaria	960	1,680	1,400	182	400	800	800	1,200	800
Pediastrum	42	50	56	51	105	72	16	56	64
Dinobryon	29,920	38,640	10,804	21,886	21,266	7,200	58,400	46,800	20,000
Ceratium	54	98	40	6	27	16	16	40	64
Codonella	6	30	15	26	85	280		16	
Polyarthra	1,560	1,885	428	268	760	308	12,000	1,840	1,440
Anuraea	3,011	3,775	1,213	896	2,108	776	2,368	3,584	1,984
Synchaeta	5	18	8						
Asplanchna	88	78	12	59	222	96	56	200	104
Nauplius	66	181	76	12	147	36		96	48
Cyclops	14	22	4	3	10		8	8	80
Daphnia	6	38	14	1	18	8		16	64
Bosmina	142	95	4	9	48	24	7	16	16
Surf. Temp.	18.5° C.			18° C.			18° C.		

the minor ones would have to be disregarded. If all 20 organisms were fully graphed, more space would be needed than in these tables, as few could be put on one graph.

Of all 20 kinds in these tables, possibly Codonella is least known to readers, to those not versed in Protozoology. It can be misidentified, as first by the writer, as a Difflugia. It is a Ciliate with lorica. Codonella belongs to sub-order Tintinnoidea or Tintinnoinea, of the order Oligotricha, which is itself placed by some writers within order Heterotricha. The group outside of a few fresh-water types is marine and pelagic.

TABLE 3.

JUNE 21 COLLECTIONS. COMPARISONS BETWEEN LAKES AND OF DEPTHS, OF THE PRINCIPAL NET-PLANKTON ORGANISMS.

NAMES OF ORGANISMS	NUMBER OF ORGANISMS PER LITER OF LAKE WATER								
	West Reservoir			East Reservoir			Miller's Lake		
	Surface	1–2 M.	3–4 M.	Surface	1–2 M.	3–4 M.	Surface	1–2 M.	3–4 M.
Coelosphaerium	208	53	1,750	69	79	332		24	136
Microcystis	136	123	324	72	16	44			16
Anabaena	16,560	12,000	68,200	19,200	8,933	19,000	504	4,800	1,200
Aphanizomenon	3,680	4,960	3,900	28,971	17,533	10,000	2,000	4,400	2,000
Melosira	400	480	800	1,027	666	1,200		1,200	12,800
Synedra	80	320		57	66				1,200
Asterionella	960	649	2,600	6,114	4,933	10,400		4,400	9,600
Fragilaria	320	565	200	914	800	1,200		400	800
Pediastrum	27	41	64	153	114	95	8	160	224
Dinobryon		80	2,400	269	221	68	800	5,200	12,800
Ceratium	419	1,008	1,136	459	421	72	96	1,696	976
Codonella		16		5	9	16		48	
Polyarthra	177	190	24	429	269	24	24	144	80
Anuraea	147	307	120	273	202	68	160	968	600
Synchaeta				67	32	44	32	32	
Asplanchna				3					
Nauplius	70	128	8	41	41	84	32	160	152
Cyclops	10	27	32	7	4	12	8	40	112
Daphnia	5	6	32	12	25	20		56	72
Bosmina	10	64		17	5	8	8	352	
Surf. Temp.	27° C.			27° C.			27° C.		

Horizontal Distribution.

There is first of all no distinct or uniform difference whatever in fauna and flora of East and West Reservoirs, or East Reservoir and its tributary, Miller's Lake. While there was for some planktonts a difference in numbers of some magnitude, this would be a much greater number of individuals from stations of one lake at one collection and often from the other lake at another collection. The chief instances of fairly well-marked differences in numbers of individuals of the two lakes, and in this case Miller's Lake is often counted in with East Reservoir, were the following. Coelosphaerium was commoner

TABLE 4.

JULY 20 COLLECTIONS. COMPARISONS BETWEEN LAKES AND OF DEPTHS, OF THE PRINCIPAL NET-PLANKTON ORGANISMS.

NAMES OF ORGANISMS	NUMBER OF ORGANISMS PER LITER OF LAKE WATER								
	West Reservoir			East Reservoir			Miller's Lake		
	Surface	1–2 M.	3–4 M.	Surface	1–2 M.	3–4 M.	Surface	1–2 M.	3–4 M.
Coelosphaerium	400	454	600	23	53	60			
Microcystis	6	75	8	289	4	8			
Anabaena	7,120	3,600	5,200	1,775	2,341	3,200	184	320	240
Aphanizomenon	1,440	960	800	1,257	933	200		800	400
Melosira	6,240	4,960	5,800	1,371	1,333	600			
Synedra	1,040	1,040	1,000	10,143	9,466	2,400	400	400	
Asterionella				114					
Fragilaria			200		133				
Pediastrum	69	56	52	20	20		24		8
Dinobryon	960		400						
Ceratium	201	318	428	1,229	682	216	64	72	88
Codonella	2	6	20	1	5	20			40
Polyarthra	245	283	140	576	500	264	88	112	128
Anuraea	856	200	244	259	313	124	80	120	200
Synchaeta	2	10	56	182	177	28	120	88	136
Asplanchna		2							
Nauplius	42	109	76	58	144	120	8	16	112
Cyclops	3	21	60	2	10	8		8	
Daphnia	2		12						
Bosmina	2	3							
Surf. Temp.	24.5° C.			24° C.			24° C.		

in West Reservoir than in East in May, June, Aug., Sept., and Oct.; Microcystis commoner in West than in East in June, Aug., Sept., Oct.; Anabaena was also more abundant in West than East in all of collections, May to Oct.; but Aphanizomenon was commoner in East Reservoir in June and Aug., but commoner in West in Sept., and Oct. Melosira was found more abundant in West than in East in April, July, Aug., Sept., and Oct. Synedra was commoner in West than in East in April, Aug., and Oct., but commoner in East May, July, Sept. Asterionella was more abundant in East Reservoir than in West in all months except Oct. Fragilaria was commoner in

TABLE 5.

August 21 Collections. Comparisons Between Lakes and of Depths, of the Principal Net-plankton Organisms.

Names of Organisms	Number of Organisms per Liter of Lake Water								
	West Reservoir			East Reservoir			Miller's Lake		
	Surface	1-2 M.	3-4 M.	Surface	1-2 M.	3-4 M.	Surface	1-2 M.	3-4 M.
Coelosphaerium	318	752	104	6			8	24	48
Microcystis	75	85	44						
Anabaena	9,976	6,200	5,700	607	759	992	240	56	
Aphanizomenon	3,200	2,880	5,200	1,886	933	600			
Melosira	6,320	7,600	10,800	1,257	1,600	800	400		
Synedra	1,680	1,920	4,000	1,086	400	400			
Asterionella		80	400			200	400	400	2,000
Fragilaria									
Pediastrum	19	3	32	1	4	4			24
Dinobryon	240						1,600		
Ceratium	14	6	8	1					8
Codonella	5	6	4	6	3	8		8	
Polyarthra	391	326	316	88	155	32	112	144	80
Anuraea	214	313	428	49	90	80	40	144	112
Synchaeta	298	168	96	37	37	12	40	64	64
Asplanchna	19	14	8	5	1				
Nauplius	149	126	80	9	41	28		32	48
Cyclops	8	16	44	5	8	8			
Daphnia									
Bosmina	21	22	24		3	8			
Surf. Temp.	23.2° C.			23° C.					

West than in East, April, and May, but commoner in East in June. Dinobryon showed a greater number by far just in Miller's Lake than in rest of East or West in May, June and Aug., but a greater number in West in July. Codonella showed a greater number in East Reservoir than in West in April, but with few differences otherwise. Polyarthra showed greater numbers in Miller's Lake in May, greater in East Reservoir in July, but in West in Aug. Anuraea showed greater numbers in West than in East in April, July, Aug., and Oct., but greater in Miller's Lake than the others in June. Synchaeta occurred in greater numbers in East than in West in April, June, and July,

TABLE 6.

SEPTEMBER 21 COLLECTIONS. COMPARISONS BETWEEN LAKES AND OF DEPTHS, OF THE PRINCIPAL NET-PLANKTON ORGANISMS.

Names of Organisms	Number of Organisms per Liter of Lake Water								
	West Reservoir			East Reservoir			Miller's Lake		
	Surface	1–2 M.	3–4 M.	Surface	1–2 M.	3–4 M.	Surface	1–2 M.	3–4 M.
Coelosphaerium	700	360	240	38	27		16	16	
Microcystis	225	189	40	15	3				
Anabaena	8,078	3,936	2,980	982	584		24	8	
Aphanizomenon	1,040	320		343	138				
Melosira	20,400	18,480	15,400	13,143	13,800	8,400	400	400	800
Synedra	1,200	160	200	857	1,000	800			
Asterionella	80	80		857	400	2,800			
Fragilaria									
Pediastrum	27	27	44	13	15				16
Dinobryon				57					
Ceratium	19	10	4	15	9	16			
Codonella	18		12	59	60	160			
Polyarthra	341	122	72	158	168	96	72	80	48
Anuraea	213	101	24	109	93	32	136	144	144
Synchaeta	242	181	48	249	303	24	136	136	128
Asplanchna									
Nauplius	176	32	36	90	75	24	24	40	40
Cyclops	19	19	36	21	28	16	8	8	56
Daphnia	3								8
Bosmina	9			6	3				8
Surf. Temp.	17.5° C.			18° C.			18° C.		

but greater in West in Aug., and Oct. These are probably differences of little significance. For other organisms and other months for the above, there were slighter differences. All can be traced on the tables, as the data for the lakes is kept distinct.

As for differences in numbers of individuals in a series of stations on the same lake, few differences would be expected except where the body of water has various distinct bays or parts, well sheltered or isolated one from another. East Reservoir shows few such areas, and no significant station

TABLE 7.

October 26 Collections. Comparisons Between Lakes and of Depths, of the Principal Net-plankton Organisms.

Names of Organisms	Number of Organisms per Liter of Lake Water								
	West Reservoir			East Reservoir			Miller's Lake		
	Surface	1-2 M.	3-4 M.	Surface	1-2 M.	3-4 M.	Surface	1-2 M.	3-4 M.
Coelosphaerium	110	184	120	3	11				
Microcystis...........	30	40	48	5	4				
Anabaena	217	371	148	53					
Aphanizomenon	80	266		57					
Melosira	12,560	23,600	15,200	2,743	4,000	2,400	400	800	800
Synedra	1,280	2,266	800	1,086	600	400	400		
Asterionella	4,776	12,666	10,400	114	267		400	1,600	400
Fragilaria									
Pediastrum	23	40	16	7	9			8	16
Dinobryon									
Ceratium		2			1				
Codonella	86	121	76	67	85	80	30	48	48
Polyarthra	205	283	100	131	156	96	64	320	160
Anuraea	235	466	140	103	132	96	32	208	120
Synchaeta	224	283	108	71	176	152	24	8	24
Asplanchna	2			27	36	16	16	24	32
Nauplius	50	74	48	62	71	64	16	72	56
Cyclops	16	18	12	14	15	8		8	16
Daphnia	1								
Bosmina	3	5		7	8			8	
Surf. Temp.	11.5° C.			11.5° C.			11.5° C.		

differences, only countless minor chance variations. West Reservoir does show a number of well marked parts. Nevertheless there were no real differences of import to be noted among the stations. This is in accord with findings in other studies. It was noted for instance by Marsh (1903) that horizontal distribution is very uniform. But one discernible difference holding for both lakes must be mentioned. Somewhat greater numbers of individuals of very many kinds were noted in northern parts of the lakes, (stations 1 and 7 on East and stations 1 and 2 on West Reservoirs). This seemed to be caused in part by winds, though in East Reservoir an effective cause would seem to be the flow towards the outlet at that northern end of the lake. In both lakes winds were frequently

TABLE 8.

MONTHLY DISTRIBUTION OF CHIEF NET-PLANKTON ORGANISMS OF WEST RESERVOIR.

NAMES OF ORGANISMS	APRIL 20	MAY 25	JUNE 21	JULY 20	AUG. 21	SEPT. 21	OCT. 26
Coelosphaerium		157	670	485	391	433	138
Microcystis		23	528	30	68	151	39
Anabaena		628	32,253	5,307	7,292	4,998	249
Aphanizomenon			4,180	1,067	786	453	346
Melosira	21,293	13,853	560	5,667	8,240	18,093	17,120
Synedra	10,927	7,267	133	1,027	2,533	520	1,782
Asterionella	17,080	175,467	1,403		160	53	9,281
Fragilaria	1,293	1,346	362	67			
Pediastrum	39	49	44	59	18	33	26
Dinobryon		26,455	827	453	80		
Ceratium	4	64	854	315	9	11	1
Codonella	64	17	5	9	5	10	94
Polyarthra	699	1,291	130	223	344	178	196
Anuraea	1,686	2,666	191	433	318	113	280
Synchaeta	61	10		23	185	157	205
Asplanchna	3	59		1	14		1
Nauplius	175	108	69	76	118	81	57
Cyclops	97	13	23	28	23	25	15
Daphnia	11	19	14	5		1	
Bosmina	24	80	25	2	26	3	3

seen to be, as seen also in wave action, towards the north and northeast. The station differences as indicated above, have been merged in the averaging necessary to produce the condensed tables.

Vertical Distribution.

Due to the shallowness of the water, little data on the vertical distribution of plankton can be secured, or in other words there will be little chance for differences in the small depths available in these lakes. The factor of different light intensities enters here in but a small way, except as turbidity governs that. The waters are of average turbidity. No exact measurements were made. The vertical differences show no uniformity that will allow any definite conclusions. The data can be seen in the tables (1–7) where the numbers for surface and depths are given fully, though averaged for all stations

TABLE 9.

MONTHLY DISTRIBUTION OF CHIEF NET-PLANKTON ORGANISMS OF EAST RESERVOIR.

NAMES OF ORGANISMS	APRIL 20	MAY 25	JUNE 21	JULY 20	AUG. 21	SEPT. 21	OCT. 26
Coelosphaerium		31	160	453	2	22	5
Microcystis		20	44	100		6	3
Anabaena		226	15,711	2,439		522	18
Aphanizomenon			18,835	797	1,139	161	19
Melosira	14,416	12,498	964	1,101	1,219	11,781	667
Synedra	5,390	8,422	41	7,334	629	886	133
Asterionella	50,695	323,109	7,149	38	67	1.352	800
Fragilaria	95	461	971	44			
Pediastrum	13	76	121	13	3	9	8
Dinobryon		16,781	186			19	
Ceratium	1	16	317	709		13	
Codonella	692	130	10	9	6	93	42
Polyarthra	587	445	241	447	92	124	181
Anuraea	450	1,260	181	199	73	78	120
Synchaeta	114		48	129	29	192	19
Asplanchna		125	1		2		24
Nauplius	142	65	55	107	26	63	48
Cyclops	63	4	8	7	7	22	8
Daphnia	14	9	19				5
Bosmina	20	27	10		4	3	3

at each level. Naturally wider discrepancies for different depths occurred at some stations, but these were compensated for by data from other stations.

Seasonal Distribution.

The monthly variation or distribution, from April to October, is shown on tables 8–10, on which all depths and stations of a lake are averaged together. Summer conditions are most fully demonstrated, but an idea of spring conditions with spring pulses for certain groups and also of autumnal increases and decreases is presented. No winter records are available. The summer seasonal record for the year 1929 may not be entirely representative, but it appears to the writer as if the only unusual thing was the somewhat abnormally lowered temperature at certain brief periods in both July and August, covering

TABLE 10.

MONTHLY DISTRIBUTION OF CHIEF NET-PLANKTON ORGANISMS OF MILLER'S LAKE.

NAMES OF ORGANISMS	APRIL 20	MAY 25	JUNE 21	JULY 20	AUG. 21	SEPT. 21	OCT. 26
Coelosphaerium		11	53		27	11	
Microcystis			5				
Anabaena		5	2,168	248		11	
Aphanizomenon			2,800	400			
Melosira	700	5,400	4,666		133	533	667
Synedra	1,867	31,067	400	267			133
Asterionella	13,800	359,600	4,666		933		800
Fragilaria		933	400				
Pediastrum		45	131	11	8	5	8
Dinobryon		41,733	6,267		533		
Ceratium	3	40	923	75	3	5	
Codonella	27	5	16	13	3		42
Polyarthra	305	5,093	83	109	112	67	181
Anuraea	685	2,645	576	133	99	141	120
Synchaeta			21	115	56	133	19
Asplanchna	1	120					24
Nauplius	84	48	148	45	27	35	48
Cyclops	169	32	51	3		24	8
Daphnia	11	27	43			3	5
Bosmina	5	13	120			3	3

the collecting dates in both these months. That is for some days or a week a lower temperature gradually lowered the water temperature at both these times. The one effect that was probably produced was the holding in check of the blue-green algæ, so that there was no very noticeable water-bloom, as has been observed and verified in small samples in other years (1928 especially) to be caused entirely by a flare-up of the same blue-green algæ shown most abundant in this investigation. Hence a relatively smaller number of these algæ in July and in August, and maybe September, would be the only difference between this record here presented and conditions in many other years.

The Monthly Distribution of the Plankton Groups.

The Cyanophyceæ (blue-green algæ) were at their maximum abundance in June, with a decrease in July and about the same numbers in August, with a continued decrease thereafter. There were none found in April and few in May.

The genus of greatest abundance is Anabaena, and it stood first in abundance of individuals at all times except in one flare-up of Aphanizomenon in East Reservoir and Miller's Lake in June and a smaller increase in East in August. Aphanizomenon on the whole was second in abundance, but was later in starting in spring. Coelosphaerium and microcystis were also prominent types. Oscillatoria was not found at any other time except in the May collections and then was in surprising numbers in fact several times as abundant as Anabaena at the same time. The numbers in both lakes happened to be of about the same size as those of the diatom Synedra found in West Reservoir this same month.

Cyanophyceæ thrive best in warm weather, as found in all investigations, and here indicated, for the June water temperature, at the day collected, was 27° C. at the surface. Whipple (1927) says that usually August would be the month for the maximum, or even September. And in his graph for Lake Cochituate he shows it even for October, which is due he notes to the great abundance of Aphanizomenon in October, a genus said to be more tolerant to cold. In this work Aphanizomenon has its maximum at the same time as other blue-greens. Lack of a continued maximum or even a greater flare-up to cause more pronounced water bloom, in July and August, (as already explained) was due to some brief periods of cooler weather, so that the surface water temperature at time of the July collection was 24° C. and of the August collection 23° C., and that of the September date dropped to 18° C. It seems as if these findings will show, if anything, that as sometimes claimed, the increases in Cyanophyceæ come quickly after onset of hot weather, and decrease as quickly after onset of cool weather.

The diatoms had their maximum abundance in the May collection, but this outstanding position was due largely to the great flare-up of Asterionella at this time. Melosira and Synedra, the other commonest diatoms, and also Fragilaria had about an equal representation in April and May, at surface water temperatures of 11° C. and 18° C., respectively. There was a great decrease in months subsequent, except that Melosira had less decrease, and was unusual among diatoms present in having again a great late summer increase, in September and October, chiefly in West Reservoir. But slight increases were noted also in Synedra and Asterionella, though that is scarcely consistent enough to be significant. Fragilaria, the least common of the four diatom genera, did not have any prominent increase, but was found in variable way in the lakes in April, May and June, with none whatever noted after July.

The productivity of Asterionella at the time of its maximum in May (collection on May 25) was the outstanding maximum of all planktonts in the lakes. The highest averages (tables 9 and 10), show for Miller's Lake 359,000 and for East Reservoir 323,109 individuals. But the maximum numbers encountered at any one station was 547,600 at E 4 at 1–2 M., followed by 521,200 at E 7, 1–2 M. In these and several other cases of higher than average numbers, they occurred at 1–2 M. depth rather than at surface or deeper, though this was not the case when smaller numbers were involved, nor for other organisms.

There was a distinct spring maximum, as frequently noticed for diatoms. Lack of collections earlier than April 20, made it impossible to say when the spring increase started. There is also here evidence for an autumn flare-up, as is often described for diatoms, but it began in late summer and was not nearly so great as the spring maximum.

Green algæ coming within the range of those taken by the plankton net were very few in kind and abundance. Only Pediastrum was found in fair numbers in most collections, and is in fact notable for its uniformity throughout the time of collections. There was a slight decrease in August, but again a compensating increase in September despite the drop of water temperature.

Dinobryon, a peculiar colonial Protozoan had its maximum in May. None were present in April, and small numbers in June and July, decreasing thereafter, with none present in October.

Ceratium a common dinoflagellate Protozoan, had its greatest abundance in June and July, with the next principal appearance in September. There was not so great a fluctuation nor so great a maximum in this genus as in Dinobryon. Fewest were present in October.

Condonella, already referred to, was prominent only in April, when it had a decided maximum, but this flare-up was only in East Reservoir, for at the same time in West Reservoir it was taken at only one station. There was a decrease in May, but rather uniform small numbers in all collections, with another increase in fall.

The rotifers of the genera Polyarthra and Anuraea, (the latter now named Keratella) were prominent planktonts in these lakes, with Synchaeta next in number, and Asplanchna occurred in somewhat smaller numbers and in fewer collections. Of other rotifers, only Anapus, (now named Chromogaster), was anything but rare, and it occurred in considerable numbers only in July.

Polyarthra and Anuraea were surprisingly similar in their general distribution and numbers throughout, with only very minor fluctuations between them. The greatest abundance of both was in May but with nearly as large a number in April. There was no marked monthly change thereafter. Synchaeta was commonest in August, September and October, and least in May and June, but no great variation was presented. Asplanchna, never very common, occurred in largest numbers in May, with a fair number in October. The distribution was peculiar because there were none whatever in September, and practically none in June and July, but a few in August.

Cyclops was the only Copepod present. Nauplius larvæ were also recorded, and both of these relatively larger-sized organisms were fairly prominent, though never abundant. Nauplius was encountered more than Cyclops, and both were in larger numbers in April than later, and both presented a monthly distribution with small fluctuations back and forth.

The Cladocera were not as common as one might expect. Daphnia, (of at least two species) was the largest common Cladoceran, and it occurred in only a fraction of the number of Cyclops. Daphnia was chiefly confined to the collections of April, May and June. The smaller water flea Bosmina was more common than Daphnia, with its maximum also in April, May and June.

On the whole Entomostraca may not be expected to reach such great maxima, according to Marsh (1903), who stated that in shallow lakes plant maxima are always outstanding, while Entomostraca and other zooplankton attain rather small numbers, but that in deeper lakes the zooplankton would attain much larger maxima than in shallow waters.

Summary.

In summarizing these findings the following points might be briefly mentioned. The blue-green algæ in number of kinds and relative abundance are about as prominent as expected in such lake waters, though with the greatest maxima probably not realized in the summer season in which the work was done. The green algæ however were not so well represented. The diatoms were also in kind and abundance well developed and prominent, with the usual dominant ones in the lead here. Among other unicellulars, the Protozoa Ceratium and Dinobryon were prominent, as they often are in lake fauna, and in addition equally prominent was Codonella. Rotifers were found in good numbers and all the types found were common lake planktonts. Possibly the Entomostraca seem somewhat deficient. This is due largely to the surprising dearth of Ostracoda. Cyclops, and a few kinds of Cladocera were fairly prominent and numerous.

The seasonal variations or distribution of the planktonts, which was one of the main parts of this work, shows quite a normal distribution, with flare-up of main or dominant groups at times that show only minor variations from what is usual in such shallow bodies of water.

It is, of course, realized that there may be great variations in plankton distribution from year to year in the same body of water, as was for instance stressed by Birge (1896), but then again Marsh (1903) pointed out that in shallow waters where plants are predominant and furnish the outstanding maxima, there is less variation than in deeper lakes. There is not likely to be a striking variation in these lakes from year to year, at least not in the kinds of plankton, nor even in the general trend of the flare-up and maxima of the several kinds and general time in which there occur, for all the observations made on some samples of plankton of other years, showed exactly the same plankton genera, and as far as data was available, also showed the same trend in their seasonal development. Only the subnormal late July and August temperatures decreased the size of the potential phytoplankton maxima, as already explained.

This paper records the main plankton types of these lakes, and their distribution in various ways, thus giving some data of the plankton biology that may serve as a beginning of a systematic plankton investigation of these lakes and reservoirs.

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